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REVIEW

Arsenic in Groundwater in Selected Countries in South and Southeast Asia: A Review

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Abstract

In the past decade, there has been increasing awareness of the occurrence of high amounts of arsenic in groundwater and its effects on human health. The best known and most studied areas with naturally high levels of arsenic are Bangladesh and the Indian State of West Bengal. Other countries where this is known to be a problem include Vietnam, Cambodia, Nepal, and Myanmar. In Thailand, arsenic has never been found naturally in groundwater, although it has been shown to occur as a result of runoff from tin mining. Currently, it appears that arsenic contamination results from transportation and deposition of arsenic-rich erosion products from mountainous areas to other areas downstream. The current WHO guideline value for arsenic in drinking water is 10 ppb, which has been adopted by many countries, while many other countries still use the previously set standard of 50 ppb.

Many technical solutions to the problem have been proposed, but currently there does not appear to be one perfect solution, although large regional water systems, such as in Bangkok, may be a good solution. If wells are drilled to provide safe water, they should be tested for arsenic before they are used. A more important issue is increasing both the amount of physical capital in a country and developing human resources in the affected countries in South and Southeast Asia.

Keywords: arsenic, groundwater, Bangladesh, Vietnam, contamination, tubewell

Introduction

In the past decade, there has been increasing recognition of the problems posed by the high amounts of arsenic in groundwater.

Arsenic can enter groundwater through human activities, such as runoff from mining wastes, as occurred at Ron Phibun in Nakhon Si Thammarat [1], or natural sources, such as ferrous and nonferrous ores, in volcanic ash, and in areas of geothermal activity. In many parts of the world, arsenic occurs in groundwater through natural geological processes. The areas in Asia where arsenic has been found through natural processes are Bangladesh/West Bengal, Mekong River Delta in Cambodia and southern Vietnam, Red River Delta near Hanoi in Vietnam, the Terai region of Nepal, Myanmar, Taiwan, and parts of China. The problem in Bangladesh is the best known and documented occurrence and has, in essence, become the reference for arsenic contamination in other parts of the world.

The World Health Organization's recommended maximum level for arsenic in drinking water is 10 ppb, and many countries including the US, EU, Japan, and Vietnam have adopted this standard, while Australia uses a standard of 7 ppb [2]. The WHO notes that 10 ppb is a provisional guideline value, because there is evidence of a hazard, but the available information on health effects is limited. This level is also the approximate detection limit for many of the most sensitive types of analytical techniques, but this amount is too small to test for accurately in the field. Many countries, including Bangladesh, Lao PDR, Cambodia, Myanmar, Nepal and Thailand [3] still use the previously issued WHO maximum level of 50 ppb, which is the detection limit for most conventional analytical methods.

This review discusses arsenic problems in South and Southeast Asia and their current status, focusing mainly on naturally occurring arsenic in groundwater.

Arsenic contamination in South Asia

Historically, surface water sources in Bangladesh and West Bengal have been contaminated with microorganisms, causing a significant amount of disease and mortality. Infants and children suffered from acute gastrointestinal disease resulting from bacterial contamination of stagnant pond water [4]. Thus, with the best of intentions, in the 1970s international development agencies led by UNICEF, along with the Bangladesh and Indian governments, initiated a project to bring clean water to the countryside, where many children were dying of diarrhea from drinking contaminated surface water. The various governmental and non-governmental agencies encouraged villagers to use "tubewells". The typical tubewell is drilled manually to between 20 and 70 m, installed with 3 m of 38-mm diameter slotted PVC casing, and attached to a lever-action hand-operated suction pump. Groundwater provides over 90% of drinking water and a large amount of irrigation water [5].

The wealthy could easily afford the tubewells and poorer people were able to receive low-cost loans from non-governmental organizations to install them near their homes. This also reduced the distances women had to go with pots and pails to collect water, reduced the dependence on more wealthy neighbors who often controlled the sources of water, and also provided relatively clean drinking water [6]. Until recently, arsenic in drinking water was not routinely analyzed by national laboratories, water utilities and non-governmental organizations (NGOs), so the body of information about the distribution of arsenic in drinking water is not as well known as for many other drinking-water constituents [7]. In Bangladesh, the main concern when installing the wells was the concentration of iron in the water, and in coastal areas, water salinity.

By the 1990s, the program was cited by many development agencies, including UNICEF, as an example of success in Bangladesh, with about 95% of the population having access to "safe" water from at least 3–4 million hand-pumped tubewells [5] (although the total number is not really known, and may be as high as ten million according to World Bank estimates). Unfortunately, shortly after this, high levels of arsenic were discovered in the groundwater, a situation which has been described as an example of Murphy's Law - if anything can go wrong, it will. [6]

In 1998, the Government of Bangladesh was offered a $44 million World Bank loan to set up an arsenic mitigation program with the Department of Public Health Engineering (DPHE), identified as the lead Government Department, and it seconded a senior official to lead the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) [8] with the goal of complete screening and mitigation of wells in 147 subdistricts by June, 2003. However, it has been reported [9] that the work had not been started as of late 2004 and that BAMWSP had asked the World Bank for a second extension.

The World Bank testing program highlighted another aspect of the arsenic problem, namely continuing doubts about the accuracy of the available data that were taken in Bangladesh and West Bengal [10-11] using an arsenic field test kit produced by Merck KGaA, based in Germany. These kits were relatively insensitive to the low levels of arsenic commonly found in drinking water and in other ways were not well adapted to conditions in the countryside of Bangladesh and elsewhere, but were used because they were the only field kits available at that time [12]. More recent kits are reported to be more reliable [13], although this has been disputed [9]. Because of this experience, there have also been subsequent doubts about the accuracy of data taken in other countries, for example, Myanmar [14]. One reason for relying on field test kits rather than laboratory analysis is the difference in cost: a test using a field test kit costs approximately US$1, whereas a laboratory test costs approximately US$9 [12]. Also, in Bangladesh and other countries, there is a shortage of both high quality testing laboratories and trained laboratory personnel [2]. Trang *et al*, [15] recently reported that a comparison of an arsenic bioreporter protocol with results from atomic absorption spectroscopy showed it had an overall average of 8.0% false negative and 2.4% false positive identifications for the bioreporter prediction at the WHO recommended acceptable arsenic concentration of 10 ppb. This was much better than the performance of chemical field test kits.

The source of the arsenic, and how it reaches the groundwater, is still highly debated. A comprehensive survey of groundwater in general, and arsenic contamination in particular, in Bangladesh, by the British Geological Survey and the Bangladesh Department of Public Health Engineering [8], showed that the greatest contamination was in the south and southeast of the country in the area near the bend in the Ganges River where it turns to flow south to the Bay of Bengal, presumably because the arsenic accumulated there when the Ganges and Brahmaputra rivers washed soil down from the Himalayas to the Bay of Bengal. The arsenic occurs in more recent, shallow deposits of clay and then dissolves in underground water by processes that are still uncertain. Aquifers deeper than 200 m are believed to be arsenic-free. The north, northwest, and hillier regions of the country have much less contamination.

One of the first hypotheses for the origins of arsenic in groundwater was proposed by a research group led by environmental scientist Dr Dipankar Chakraborti of Jadavpur University in Kolkata [16]. In this, arsenic was associated with iron pyrites and enters the aquifers by an oxidation process. Thus, overuse of groundwater (mainly) for irrigation, lowers the water table, allowing air to reach the contaminated clay and release arsenic. Other theories that have generally been discarded include: (1) construction of barrages on the Ganges River by India in the 1970s, which reduced the amount of water flowing into Bangladesh during the dry season to the point where oxidation of iron pyrites was possible and also making irrigation necessary, (2) arsenic in wooden power poles, and (3) fertilizer use.

Following the comprehensive survey by the British Geological Survey and the Bangladesh Department of Public Health Engineering, another hypothesis was proposed and this is currently the most favored theory for explaining the arsenic data [8]. They believe that the arsenic is naturally occurring and is the result of a number of poorly understood release mechanisms. It appears to be related to the burial of fresh sediment and generation of anaerobic groundwater that probably occurred several thousand years ago. They believe that the arsenic was desorbed and dissolved from iron oxides that had earlier scavenged the arsenic from river water during transport as part of the normal load of river sediment.

A more recently documented arsenic problem has been found in the lowland Terai region of Southern Nepal along the flood plains of the Koshi and Bagmati Rivers. This groundwater is an important source of water for both domestic and agricultural use. The extent of the problem is difficult to determine, since little has been published in peer-reviewed journals and much of the existing data are in reports from various development agencies; the best review of the existing data is found in Smedley [14]. The Terai contains approximately 800,000 tubewells, about 60,000 installed by government agencies or NGOs mainly in mid- to late-1990s. As of September, 2003, according to the National Arsenic Steering Committee, 69% of 25,000 samples had arsenic concentrations <10 ppb, while 31% were above, with 8% >50 ppb. Tandulkar [17] found some seasonal differences in arsenic concentrations between pre-monsoonal and post-monsoonal concentrations.

There are also recent reports of high arsenic concentrations in the Indian state of Bihar, which is located just below the Terai region, upstream on the Ganges River from West Bengal and Bengladesh [18].

Solutions to the problem in Bangladesh and West Bengal

The arsenic contamination in Bangladesh and West Bengal first became widely known about a decade ago, but according to some prominent Indian researchers, very little concrete action has been taken to solve the problem. Many villagers continue to drink water that is high in arsenic and are not even aware of either this or its effects on their health. [18].

Part of the problem is that no perfect technology exists for providing safe water to poor communities plagued by the arsenic problem. Surface water in Bangladesh is free of arsenic, but highly contaminated by pathogenic microorganisms. Filtration methods reduce microbial levels in the water, but not enough to make it safe to drink. Various adsorption methods generally involve the use of ferric materials of various types; unfortunately, disposing of contaminated sludge is a problem for all arsenic filters [19].

Much of Bangladesh and West Bengal consists of two overlying aquifers, a shallow one that extends from about 10 m to 50-70 m, and a much deeper one 200 m or farther underground and separated from the shallow one by a layer of clay. Thus, one possible solution to the problem is to drill deeper wells, as has been done in parts of Bangladesh and West Bengal, to provide relatively uncontaminated water. One continuing concern is that in the process of drilling the deeper wells, the deeper aquifer might become contaminated by arsenic-bearing water flowing down from the shallow aquifer through the boreholes themselves [5].

The ultimate technical solution to the problems with arsenic in groundwater appears to be to move away from individual tubewells as a source of drinking water and towards a regional water system that supplies a large number of people. Thus, even if groundwater is used as a source of domestic water, with a large number of users it is possible to use sophisticated water treatment techniques which can lower the arsenic levels down to relatively safe levels. At the same time, it is also possible to use the sophisticated laboratory techniques necessary to provide the accuracy necessary to determine if arsenic levels in the water continue to remain below the 10 ppb WHO guideline. However, if local surface water becomes polluted and community wells are drilled tap relatively clean groundwater, these wells should be carefully tested before they are used.

This has been done in Bangkok, where water for domestic use comes from surface water that is treated in municipal water treatment plants. Thus, even though geology of the Chao Phraya River Valley is similar to the Ganges Delta in Bangladesh, any arsenic in the drinking water becomes almost irrelevant [20]. This is possible if the technical and scientific community works constructively with large international organizations, such as the World Bank and UNICEF, which have the organization and capital to scale up mitigation [21].

Aggravating the problem in Bangladesh and India is that arsenic contamination is mainly a problem suffered by the rural poor in general (and rural women in particular, who generally have to collect drinking water) who have little effective voice in making decisions in Bangladeshi society [22]. Thus, a move away from individual tubewells may mean a return to women having to walk long distances with their water containers and in general a return to "dependence on better-off neighbors" [6].

While in theory the social solutions seem simple, in fact, in many developing countries like Bangladesh, this can be very difficult because of an almost overwhelming number of societal problems and physical infrastructure problems to be overcome. In these countries, there must be investment in both physical capital (laboratories, health clinics, training centers, etc) and also in human resource development. The plans for this capacity building must also be transparently designed and involve all of civil society [23]. In countries where social and physical infrastructure is already in place, dealing with the technical problem of arsenic in groundwater should be relatively simple.

Any solution proposed must have support and active participation from the local communities, since in South Asia, arsenic contamination of groundwater has mainly been a problem in rural areas. In rural areas, it is common for well-educated urban technical experts to visit a poor rural village in their expensive vehicles and tell the villagers that they should not be drinking water that is high in arsenic and then, following government policy, the pump on the well is painted either red (high arsenic levels) or green (for 'safe' arsenic levels). If the expert returns, the villagers know what he/she wants to hear about what they are now drinking and also quickly learn that one should not really believe what the technocrats are telling them [24]. Often, rural populations are less informed and politicized than urban populations, and thus have less influence in the political process. This means that there is less incentive for politicians to address arsenic contamination in rural areas [19].

Southeast Asia

The first case of arsenicosis in Thailand was reported in 1987 in Ron Phibun District of Nakhon Si Thammarat Province, in the southern peninsula [1]. Arsenic there may be from both point sources (leachate from ore dressing plant wastes) and diffuse sources (underground placer deposits) [25].

Although arsenic has never been reported to occur naturally in Thailand, some researchers have speculated that the Chao Phraya River valley could have a groundwater arsenic problem, since it contains relatively young sediments that could develop a combination of geochemical conditions, such as reducing conditions, or oxidizing, high pH that allow the release of arsenic, combined with conditions that prevent the arsenic from being flushed from the aquifer [14, 26].

To assess the possibility of arsenic in the Chao Phraya River Basin and possible public health issues, Kohnhorst *et al* [20] conducted a survey of groundwater sources near the river. The survey area was in the Buddhamonthon Subdistrict of Nakhon Chaisi District, Nakhon Pathom Province and is typical of the lower Chao Phraya Basin. The study wells tapped relatively shallow aquifers, at depths of 80 to 200 m, and were all equipped with electrical pumps to deliver the water to above-ground storage tanks on towers. In all, 37 different wells were tested, some repeatedly. Including surface water tests, over 60 tests were run. For the great majority of wells, 5 mg/l of arsenic or less were detected. This was true in both the rainy and dry seasons, though positive correlations with rainfall have been noted previously [27-28]. The mean of all tests was just 11 mg/l. Well depth (as reported by the owners) did not show any relationship to arsenic concentration, and other factors (iron, pH, and conductivity) showed little variation between locations.

Thus, it appears that arsenic in groundwater is not of public health significance in the Central Thailand region, since most households have easy access to high-quality treated water. For the western Bangkok suburbs, where this survey took place, completion of the Mahasawat Water Treatment Plant in 1996 has made the possibility of arsenicosis even less likely [20]. The few wells that remain in use exceed 100 m in depth. The depth requires the use of powerful electric pumps to raise the water into water towers, with much concurrent turbulence. The water is therefore well-oxygenated; in the tanks, any solids usually settle before the water reaches end users. Thailand may therefore provide a model for other developing countries facing possible groundwater arsenic problems.

One of the more recently documented problem areas is the Red River Basin, near Hanoi. [28]. The high arsenic concentrations are in the Thai Binh aquifer, a low-lying flood plain which (like the Mekong) contains very recently deposited river sediment that is rich in peat and other organic reductants. It is also subject to seasonal (monsoonal) flooding with a high stage amplitude.

The Vietnamese capital, Hanoi, is located in the upper part of the Red River Delta and has a population of approximately 11 million people. In the past decade, people in the countryside have stopped using surface water or water from shallow dug wells and have begun to use private tubewells, similar to what has happened in Bangladesh. In Hanoi, eight major well fields supply water to city treatment facilities [28].

The study looked at private tubewells in four rural districts around Hanoi, sampling approximately 50 wells in each district. The average arsenic concentration for the rural areas was found to be 159 ppb with a range of 1 to 3,050 ppb in rural groundwater samples from small, private tubewells. Analysis of raw groundwater pumped from the lower aquifer for the Hanoi water supply indicated arsenic levels of 240-320 ppb in three of eight treatment plants, and 37-82 ppb in another five plants. Aeration and sand filtration used in the treatment plants for iron removal lowered the arsenic concentrations to levels of 25-91 ppb, but 50% remained above the old Vietnamese arsenic standard of 50 ppb, in use when the study was conducted. Since Vietnam has recently adopted the WHO guideline value of 10 ppb [2] most of these samples would probably not meet the standards. Because of the proximity of the study area to Hanoi, it is possible that urban wastewater discharge may have contributed to the high levels of arsenic seen in the groundwater [28].

More recently, Trang *et al* [15] determined the arsenic content of 83 samples of groundwater from the Red River Delta and of 111 water samples from the Mekong River Delta by both atomic absorption spectroscopy (AAS) and arsenic bioreporter-based test. In the Red River Delta, the minimum arsenic content (in ppb) was 1.3, the maximum 460, and the average 140. For the Mekong Delta, the minimum concentration was < 1 ppb, the maximum 850, and the average 39.

A number of small-scale studies have shown that arsenic exists in the aquifers of Cambodia and the Mekong River Delta in Vietnam. Arsenic concentrations are typically less than 10 ppb, although there are scattered areas with concentrations of 10-30 ppb [29]. The highest concentrations are 600 ppb in iron and organic-material rich flood plain sediments where there are very large flood-related fluctuations in water levels. High arsenic waters are found in shallow aquifers (0-5 m in depth) and in aquifers at 100-120 m. They concluded that there is much less of a problem in these areas than in Bangladesh/West Bengal, Nepal, and the Red River valley of Vietnam, being essentially a low-level problem except for a few "hot-spots" of extremely high arsenic concentrations, although it appears that the shallow aquifer in the Mekong Delta has higher arsenic concentrations than the shallow aquifer in Bangladesh [30].

Stanger has argued that arsenic levels in rivers in South and Southeast Asia can be characterized by whether or not their headwaters have drained from Qamdo-Simao Province, now or in the past, and therefore, have transported and deposited arsenic-rich erosion products downstream. On this basis, the Irrawaddy, Chindwin, Salween, Mekong, Jinsha Yangtze, Black Da, and Red River basins all have risk of high arsenic concentrations [30]. Also, the Mekong Delta and the Ganges-Brahmaputra-Meghna Delta in Bangladesh are fed by monsoonal rivers carrying huge loads of sediment and rise several meters during the rainy season causing massive flooding. Both deltas contain silty sediments with a large amount of iron and organic matter (peat, buried mangroves, reeds, and rhizomes from agriculture) which creates ideal conditions for concentrating arsenic by adsorption on an $FeO{\cdot}OH$ substrate [30].

There is arsenic contamination of groundwater in Myanmar, but information is scant and little has been published in peer-reviewed journals, with one of the few reviews on the topic being that of Smedley [14]. Traditionally, sources of water for domestic use in Myanmar were dug wells, ponds, springs, and rivers. However, since the early 1990s, many shallow tubewells have been dug in the shallow aquifer of the Irrawaddy Delta. It is estimated that there are more than 400,000 tubewells in the entire country of Myanmar, with more than 70% privately owned. Arsenic concentrations in groundwaters have not been determined in detail and most investigations are in the early stages [14].

In early 2001, Save the Children (UK) conducted a comprehensive water quality survey [31] in approximately 550 square kilometers of four Ayeyarwady Division Townships (the southern delta area). Overall, water samples containing arsenic levels > 0.01mg/l (WHO Standard) were detected in 45% of the tubewells examined, while 21% of the samples exceeded 0.05mg/l, the proposed Myanmar National Standard. The remaining 55% samples showed no measurable level of arsenic. Smedley [14] noted that much of the data were taken with the relatively inaccurate Merck arsenic test kit and so there are concerns about inaccuracy.

In 2002, the Department of Medical Research (Lower Myanmar) conducted a small- scale survey to determine the arsenic content of groundwater in two townships of Ayeyarwady Division [32]. The survey collected water samples from shallow tube wells or dug wells, along with water samples from household drinking pots for each well from which it was drawn. Approximately 67% of the water samples had arsenic level > 50 ppb, but only 37% of the household water from drinking water pots had arsenic levels > 50 ppb, indicating that the arsenic level when consumed was lower than the water sources from which it came. In the survey areas, people usually keep water overnight in a large open vessel or pot, or filter the water with cloth, which may reduce the arsenic content of the water [32]. From similar surveys in Bangladesh, high amounts of iron are often found in the same water as high amounts of arsenic, and often the iron can be made to react with the arsenic and precipitate both. This may have happened in this study, but further work would be necessary to confirm this.

The arsenic problem and its effect on health in Myanmar is relatively new and the full magnitude and scale of the problem is still unknown. However, based on geology and geography, there is a serious risk of arsenic accumulation and groundwater contamination throughout the Irrawaddy-Chindwin Basin [30]. According to the reports reviewed by Smedley [14], it appears that around 15% of the groundwater has arsenic concentrations higher than 50 ppb, with the number presumably higher if the newer 10 ppb standard is applied. Interestingly, around 8% of dug wells appear to be above the 50 ppb limit for arsenic, something that is generally not seen in Bangladesh.

Conclusions

Arsenic has been known to be a public health issue for a number of years with well documented cases of high arsenic levels in drinking water in Taiwan and South America. It is estimated that more than 100 million people, mainly in rural areas, are at risk in Bangladesh, the Indian State of West Bengal, Vietnam, and other countries in South and Southeast Asia where groundwater that is higher than the 10 ppb WHO guideline value for arsenic is consumed [33]. Most of the existing wells are less than 10 years old and the number of people affected is still relatively small because it can take many years for the symptoms of arsenicosis to develop [4].

There are several stages in the symptoms of arsenicosis [6, 34]. In the first stages, the symptoms include skin lesions, melanois, and keratosis, where the palms of the hands or the soles of the feet become hard and lose sensation. Over time, as arsenic intake continues, the patient has leucomelanosis characterized by white spots mixed with black, swollen legs, and cracked and bleeding palms and soles (hyperkeratosis). These sores can make walking and working difficult, easily becoming painful and infected. In addition, the kidneys, liver, and nervous system begin to malfunction. After about 20 years, the sores have become gangrenous, cancers begin to form, and the kidneys or liver begin to fail. It is thought that arsenic is an endocrine disruptor, functioning by suppressing the ability of the glucocorticoid receptor to respond to its normal hormone signal, even in non-toxic doses [35].

There are also indications that malnutrition is a factor contributing to the risk of arsenicosis, particularly in Bangladesh and West Bengal, where malnutrition is widespread [36]. However, arsenic poisoning is also a problem in areas such as Chile and in parts of North America, which are relatively well-nourished. Added to the nutrition problem is the fact that it is difficult to make people understand that clear, tasteless water can be harmful, unlike, for example, cigarette smoking [24].

Arsenic first became widely known as a health issue in drinking water in South Asia in the mid- to late-1990's when public health workers discovered that large numbers of mostly rural people were drinking groundwater from small tubewells that they had been encouraged to install to tap the relatively unpolluted shallow aquifer for clean drinking water. Extensive surveys of arsenic levels in tubewells and other scientific studies have shown that the arsenic results from transport and deposition of arsenic-rich erosion products downstream [6].

Surveys of tubewells in Vietnam, Cambodia, and Myanmar have recently shown that there is a similar problem of high arsenic concentrations in the groundwater and transport and deposition of arsenic-rich erosion products downstream has also been theorized to be the source of these high arsenic levels [14]. Currently, considerably less is known about the extent of the problem in Southeast Asia in contrast to the well-documented problems in South Asia.

Because the problems are similar in South Asia and in Southeast Asia, the solutions will also be similar. The easiest method of resolving the problem is to move away from individual tubewells as a source of drinking water and towards a regional water system that supplies a large number of people, although this may not be possible in the short-term. If local surface water becomes polluted and community-wells tap relatively clean groundwater, these wells should be carefully tested before they are used. These solutions should be relatively easy to implement in Southeast Asia, because a relatively well developed social and political infrastructure is already in place to implement these remedies.

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